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DEVELOPMENT OF A HIGH-SPEED H-ALPHA CAMERA SYSTEM FOR THE OBSERVATION OF RAPID FLUCTUATIONS IN SOLAR FLARES

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ABSTRACT

We have developed a solid-state digital camera system for obtaining Hα images of solar flares with 0.1 s time resolution. Beginning in the Summer of 1988, this system will be operated in conjunction with SMM's Hard X-Ray Burst Spectrometer (HXRBS). Important electron time-of-flight effects that are crucial for determining the flare energy release processes should be detectable with these combined Hα and hard X-ray observations.

Charge-injection device (CID) cameras provide 128x128 pixel images (0.8 arc-sec/pixel) simultaneously in the Hα blue wing, line center, and red wing, or other wavelength of interest. The data recording system employs a microprocessor-controlled, electronic interface between each camera and a digital processor board that encodes the data into a serial bitstream for continuous recording by a standard video cassette recorder. With a combined data rate of 4 Megabaud for a three camera system, a typical one week observing run is expected to produce approximately 100 gigabytes of data at a storage cost of approximately $1/Gigabyte. Only a small fraction of the data (i.e. data containing flares) will be permanently archived through utilization of a direct memory access interface (a DRE-11CC) onto a VAX-750 computer.

In addition to correlations with hard X-ray data, observations from the High Speed Hα Camera will also be correlated and optical and microwave data and data from future MAX '91 campaigns. Whether the recorded optical flashes are simultaneous with X-ray peaks to within 0.1 s, are delayed by tenths of seconds or are even undetectable, the results will have implications on the validity of both non-thermal and thermal models of hard X-ray production.

I. INTRODUCTION AND SCIENTIFIC BASIS

i. Introduction

A significant fraction of the science effort during the last solar cycle has been directed toward observations of solar flares with high time resolution. Correlations of subsecond x-ray variations with UV and microwave variations have placed important constraints on models of solar flares. Microwave images obtained with the VLA have good spatial resolution but relatively poor time resolution (~3 s). Ultraviolet images obtained with the Solar Maximum Mission (SMM) can have good time resolution, but at the expense of observing at only one or a few pixels. Clearly, there is a great need for new correlative studies of solar flares to achieve high time resolution and high spatial resolution simultaneously in order to resolve effects such as those resulting from electron time-of-flight. These effects are crucial for determining causal relationships among emitting components and in identifying the flare energy release process or processes.

ii. Hard X-Ray Emission

In the non-thermal electron beam model for hard X-ray emission, electrons accelerated near the top of a flaring coronal loop stream along magnetic field lines until they reach the relatively dense layers of the lower corona and upper chromosphere. Here they produce hard X-ray bremsstrahlung at energies ranging from tens of keV to several MeV (cf. Brown, 1971; Emslie, 1980). Electrons with energies of ~35 keV produce many of the X-rays seen by the Hard X-ray Burst Spectrometer (HXRBS) on SMM. For typical flare loop dimensions of 1-5 x 10^4 km, electrons of this energy should traverse the loop in 0.1-0.5 s or longer depending upon their pitch angle with respect to the loop's magnetic field. Observations on timescales of ~0.1 s or less are required to resolve electron time-of-flight effects.

With the high-time resolution of HXRBS on SMM, hundreds of fast X-ray spikes with durations of less than 1 s and rise and decay times of some tens of milliseconds have been detected (Kiplinger et al., 1983). The existence of such variations in hard X-rays offers the opportunity to correlate variations at differing energies on timescales that are considerably less than one second. Note for non-thermal models, the observed hard X-ray time profile is the convolution of the temporal evolution of the electron acceleration process with propagation effects associated with the beam of electrons interacting in the target (cf. Emslie, 1983). Alternatively, the relevant timescales in thermal models stem from the bulk heating and the cooling of the source through, for example, conduction, convection, expansion and radiation (cf. Smith and Auer, 1980). Thus, the observation of hard X-ray variations on timescales as short as, or shorter than, the anticipated timescales can place constraints on some or all of the above processes.

iii. Expected Response in Hα

The Hα emission line (λ6563A) can provide spatial information very accurately if it can be shown that there is a good temporal correlation

between the Hα and hard X-ray time profiles. In a CCD study of Hα fluctuations, Kampher and Magun (1983) have shown that there is a component of the Hα emission that shows impulsive variations that are coincident with microwave spikes. However, with a time resolution of only 1.4 s, coincidence could only be established to within 2 s. In a photographic study by Kurokawa (1986) with 1 s time resolution, coincidence of hard x-ray spikes with Hα fluxes, as measured in the blue wing, was established to within one second. This study also concludes that the impulsive phase of an Hα flare is characterized by fast and successive brightenings of many flare points with point sizes of 1 arc-sec or less. However, there may be some ambiguity in interpreting Hα results since the line is produced from plasmas with low effective temperatures, $T_{eff} \sim 10^4$ K, which are generally associated with cooler thermal components that develop during a flare. Indeed, both of the the Hα studies described above did identify both impulsively varying bright points and bright points or patches which vary on much slower timescales.

Detailed observations in Hα can provide a wealth of diagnostic information on differing physical processes. Calculations of the sensitivity of Hα profiles to electron beam fluctuations by Canfield and Gayley (1985) describe the temporal response of the spectral line. An instantaneous injection of an electron beam into the chromosphere is expected to produce an impulsive rise in Hα intensity over the entire line profile on a chromospheric heating timescale, $t_h \simeq 10$ ms. In addition to this major impulsive rise, the blue wing of the line is expected to show a secondary response on the hydrogen ionization timescale, $t_i \sim 0.3$ s. A third effect of the rapid injection of energy into the chromosphere is the creation of a high pressure region and its resultant compression wave. This wave, in turn, forms a chromospheric condensation whose emission begins to dominate the red wing of the line, and to some extent the line center, approximately 1 second after the impulsive rise. For this reason, and the fact that Hα intensities generally increase from thermal plasmas that build up during the flare, observations in the blue wing of Hα may provide the greatest contrast for observing impulsive brightenings resulting from subsequent electron beam injections later in the flare.

In summary, the expected response of Hα to a rapid onset of an electron beam would be for the intensity in the entire profile to rise within 10 ms of the rise in hard X-ray fluxes, with a smaller, secondary rise in the blue wing following by about 0.3 s. Finally (after 1.0-1.5 s) the red wing and, to a lesser degree, the line center should show a secondary rise due to hydrodynamic effects. Few of these effects have been detected or even studied observationally. This is due to the lack of the proper instrumentation and to the vast quantities of data that must be collected to insure sufficient temporal and spatial sampling of the flare.

II. EXPERIMENTAL DESIGN AND OPERATION

i. The Digital Hα System consists of the following components:

Detectors: The detectors are solid-state charge-injection device (CID) cameras which feature a high signal-to-noise ratio and which provide 128x128 pixel images at the rate of 10 frames/s. A CID camera has been chosen since it allows shutterless operation; furthermore, the ultra-low noise

levels of CCDs are unnecessary in this high-light-level/short exposure-time environment. The system is initially a two camera system with one camera operating at center-line Hα and the second camera operating 1.1 A in the blue wing.

Recording System: Each data recording system (one for each camera) consists of a computerized interface and controller which connects the camera to a commercially available digital processor board. This board encodes the data for recording onto standard video cassette recorder (VCR) tapes. The interface serializes the digital camera data and adds absolute timing information (accurate to 1 ms) to the data stream. The VCR is a means of temporarily storing the large quantities of data obtained. With each camera yielding ~5 gigabytes of data each observing day, a seven day observing run would produce ~100 gigabytes of information that can be stored on ~25 reusable VCR tapes. (One hundred gigabytes is equal to the total amount of data returned by SMM in 19 months.) Computer archiving of data recorded during flares is only necessary for the small fraction of data that will be studied. Archiving of the digital data utilizes a direct memory access interface board (known as a DRE11-CC) in a VAX computer which copies the data onto a hard disk and ultimately onto magnetic tape.

Optical System: The telescope to be employed initially is a 40-cm Cassegrain telescope at Goddard stopped down to 15 cm by a heat rejection filter. The off-axis beam enters a 0.5 A (FWHM) dual-passband Hα filter. As shown in Figure 2. one passband is situated at line center with the other situated 1.1 A in the blue wing. The passbands are separated by a polarizing beamsplitter and directed to two of the cameras. Although it is initially configured to be a two camera system, a third camera can be added which will observe at the wavelength of H$\alpha \pm$300A. The third camera utilizes a beam from a standard beamsplitter that is situated in front of the dual-passband Hα filter system. With an effective focal length of 7.3 meters, the 128x128 pixels of the CID cameras correspond to a projected field of view of 1.7'x1.7' field of view at 0.85" per pixel.

ii) Observing Program:

With a startup time of two hours or less (instead of two days for Sacramento Peak), we can respond within the early growth stages of an active region when the most impulsive flares tend to occur. However, since only 10% of flares exhibit subsecond time variability (Kiplinger et al., 1983) and since only a fraction of active regions display a propensity to produce such flares, we do not intend to observe on a routine daily basis. Rather, we will decide to observe in a fashion analogous to the "bumping" decisions we currently make for our Sacramento Peak observations. We anticipate observing for five- to seven-day intervals perhaps ~4 times per year under conditions of moderate solar activity (i.e. initial stages of the solar cycle).

One of us, Alan Kiplinger, has proposed to NASA and NSF to assume the role of MAX '91 coordinator and to carry out research at the University of Colorado in Boulder. Operation of this camera is part of his proposed research; therefore, after the high-speed system becomes operational at Goddard

(and assuming that Kiplinger does move to Colorado) we anticipate moving the camera system to a 45-cm cassegrain telescope at the University of Colorado. The Colorado location will continue to provide a 100% availability of telescope time (during daytime hours) and a short startup time. Moreover, relocation to Boulder will provide far better seeing and transparency conditions than are typically present at Goddard. Moving the instrument westward will also provide two more hours of overlap in observing time with any collaborative programs that may be operating from New Mexico to Hawaii. Observations from Boulder will also mark the curtailment of the Sacramento Peak program, thus providing a significant increase in observing time on the Vacuum Tower Telescope for other important Max '91 programs.

iii) Data Analysis

As a principal investigator in an ongoing CCD program with the National Solar Observatory, Kiplinger has developed the necessary software to analyze data produced by the new high-speed system. Interactive routines that perform field flattening corrections and also generate time profiles from any selected part of an image are maintained on the SMM Data Analysis Center (DAC) VAX. Both the SMM DAC and the APAS Vaxlab Computer at the University of Colorado have Grinnell image processing systems that can utilize this software. Thus, the analyses will be carried out in Boulder once the camera system is relocated.

A major part of the analysis is to study temporal correlations of hard X-ray fluxes measured with HXRBS with optical fluxes from various parts of the images at all of the observed wavelengths. The data would also be compared with the high-spectral, low-temporal resolution data to be obtained by Richard Canfield in Hawaii when simultaneous observations are available. Although comparisons with HXRBS data will be an initial focus, data from other instruments such as the Gamma Ray Imaging Device (GRID) to be proposed within the MAX '91 balloon program and BATSE of the Gamma Ray Observatory would be of great interest.

iv) Current Program Status and Schedule

Current Status:

As of June, 1988, the development of the high speed Hα system stands as follows:

- Construction of the optical/mechanical system has been completed.

- Major components of the electronic interface of the first camera have been constructed and we are awaiting arrival of the microprocessor that directs the data flow.

- Single camera operation at Goddard is expected by the summer of 1988 with two camera operation beginning by late 1988.

Schedule:

An approximate schedule for development of the high-speed system is as follows:

1988

Fabrication of the second interface should begin by the summer of 1988 with two camera operation beginning by the fall.

Construction of the third interface and procurement of the additional camera and recorder should begin by late 1988.

1989

Move of the two camera system to Boulder. Due to the similarities of telescopes at the two locations, it is expected that operation at Boulder could begin within a few days of the arrival of the instrument.

The Hα filter previously purchased by Goddard in 1971 will be refurbished in order to remove serious internal reflections. This filter will utilize light from the third beam for Hα red-wing observations.

Development of the mechanical and optical system for the third camera should be completed, along with the interface for the third camera.

1990

Three camera operation is expected by early 1990.

III. REFERENCES

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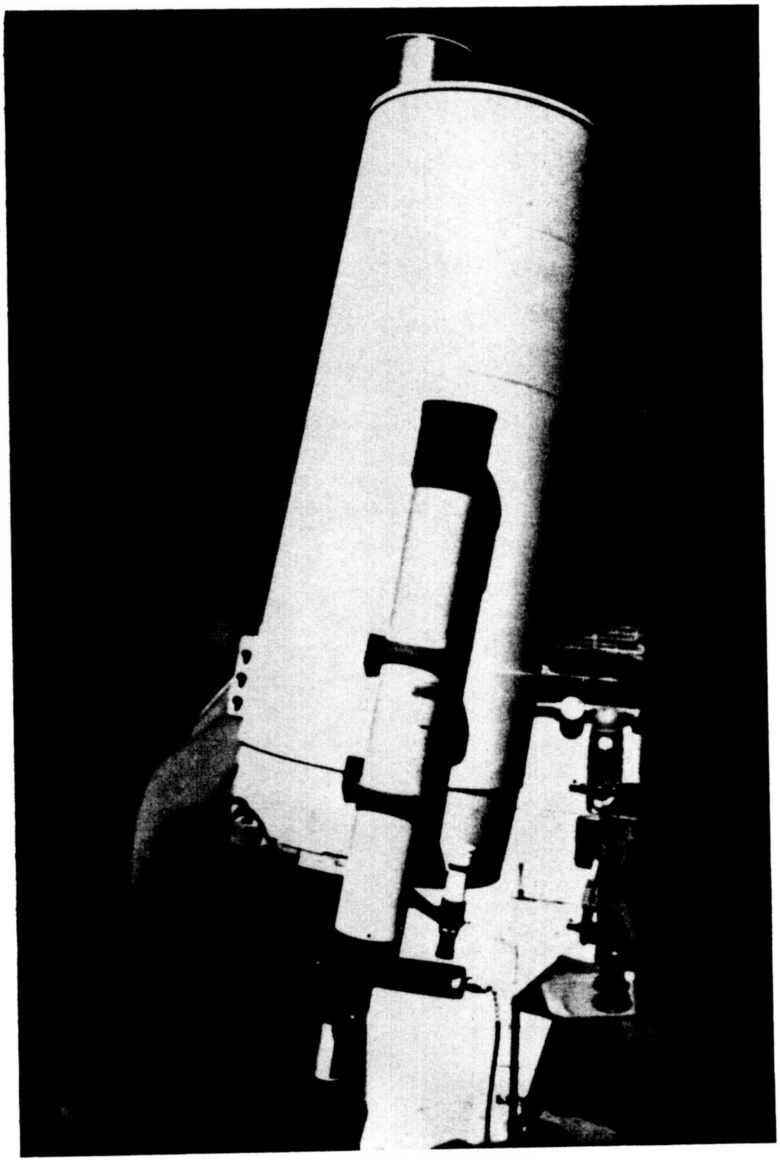
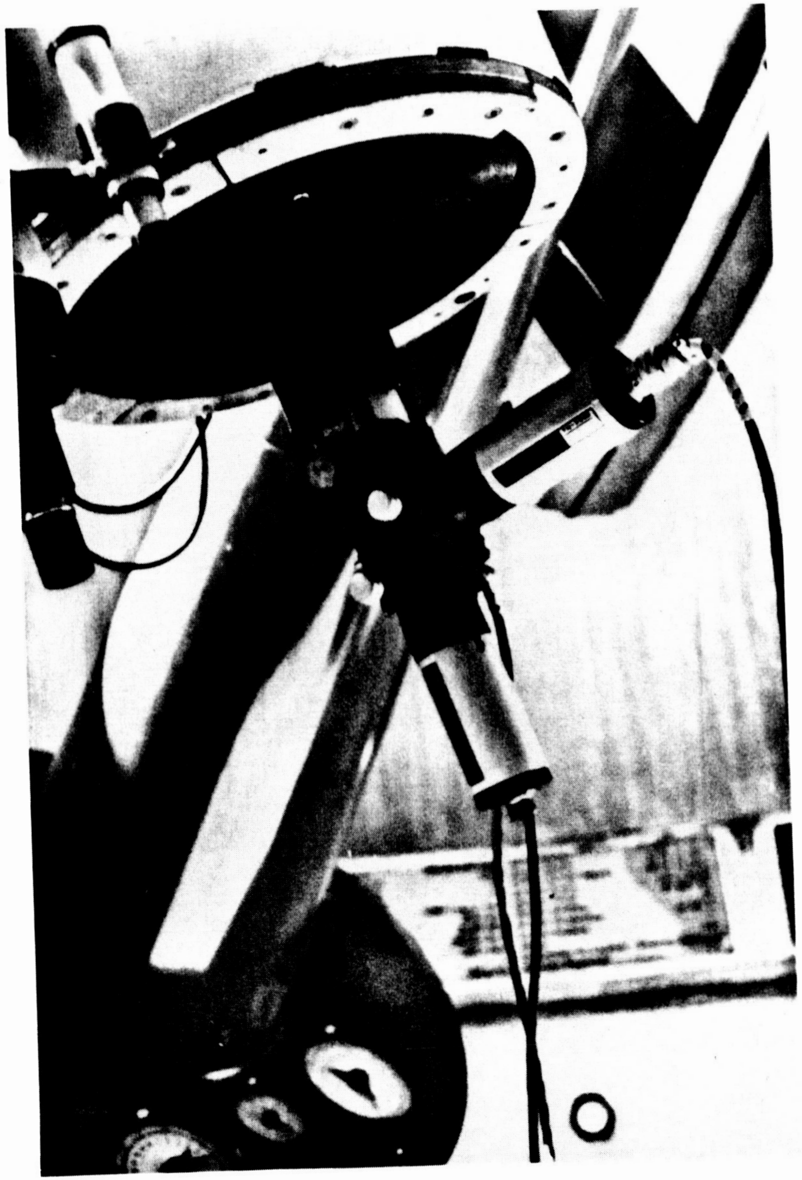
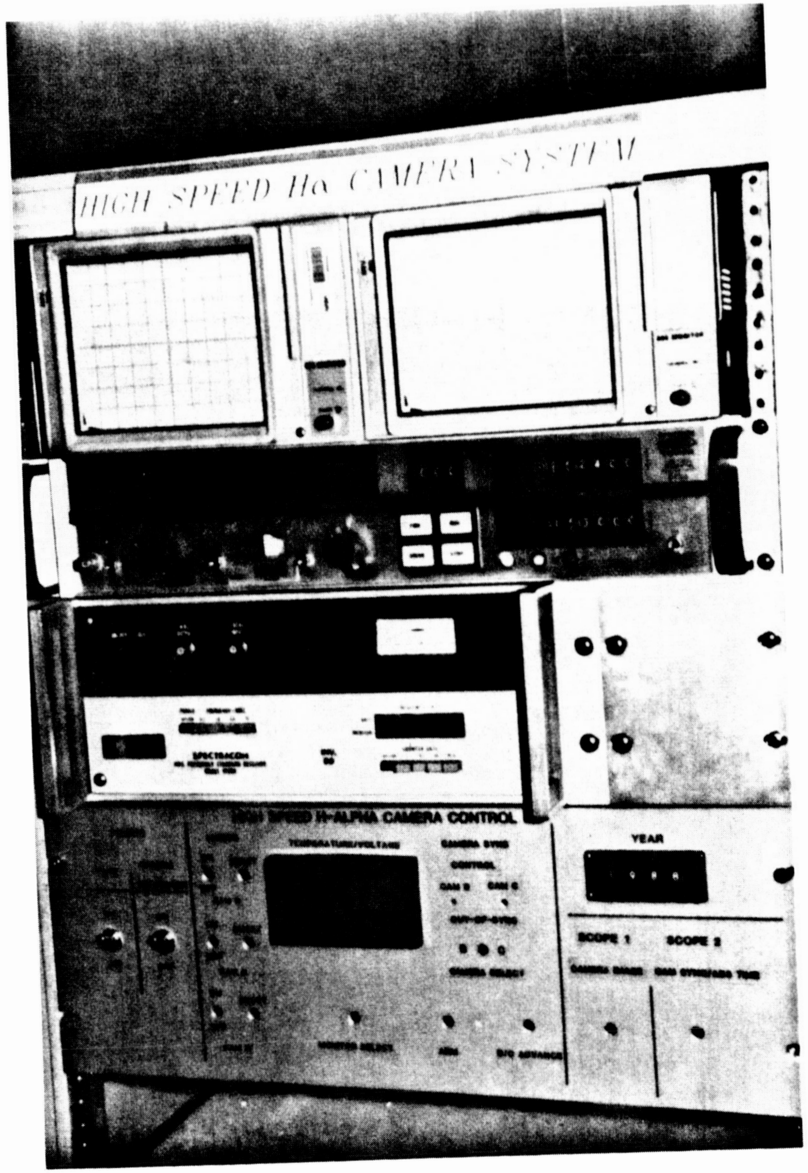


NASA/Goddard 0.4 m (16-inch) Cassegrain Telescope with 6-inch heat rejection filter (top) and Dual Camera Assembly (bottom).



H-α Filter and Dual Camera Head Assembly



Camera Displays, Time Encoder and Camera Control Panel

Six-inch aperture stop on 0.4 m telescope. The aperture stop houses the heat rejection filter.